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# BATCH DISINFECTION OF TREATED WASTE-WATER WITH CHLORINE AT LESS THAN 1 DEGREE C

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Environmental Protection Agency

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The results indicated that both chlorine demand and the rate or extent of coliform reduction were decreased at the low temperature. The disinfecting ability of chlorine varied significantly at less than 1°C, among the four effluents studied. These effects did not in themselves negate the effectiveness of chlorine as a disinfectant at low temperature because the previously stated minimums were easily met in effluent from all sources. However, higher bacterial quality can be expected from batch treatment than is found in most short-circuit plagued operating contact chambers.

The only real measure of satisfactory disinfection is the number of enteric bacteria being discharged into the receiving water. An arbitrary chlorine residual after a predetermined contact time cannot be considered prima facie evidence of satisfactory disinfection because of the variable disinfecting ability of chlorine. The chlorine residual:contact time relationship must be established for each effluent at the lowest temperature encountered in the system. (EPA)

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# BATCH DISINFECTION OF TREATED WASTEWATER WITH CHLORINE AT LESS THAN 1°C

by

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## ABSTRACT

A laboratory study was conducted in which the batch treatment technique was used to gain some insight into chlorine disinfection of waste treatment system effluents at less than 1°C. One primary and three secondary effluents were examined at the low temperature with parallel control samples at 25°C. Effluent disinfection was considered minimally effective if, after one hour contact time in the presence of 1 mg/l total chlorine residual, there were no more than 1000 total and 200 fecal coliforms/100 ml.

The results indicated that both chlorine demand and the rate or extent of coliform reduction were decreased at the low temperature. The disinfecting ability of chlorine varied significantly at less than 1°C when all four effluents were compared. These effects did not in themselves negate the effectiveness of chlorine as a disinfectant at low temperature because the previously stated minimums were easily met in effluents from all sources. However, batch treatment is not plagued with short-circuiting as are most operating contact chambers, so a higher bacterial quality could be expected after the contact period.

The only real measure of satisfactory disinfection is the number of enteric bacteria being discharged into the receiving water. An arbitrary chlorine residual after a predetermined contact time cannot be considered prima facie evidence of satisfactory disinfection because of the variable disinfecting ability of chlorine. The chlorine residual:contact time relationship must be established for each effluent at the lowest temperature encountered in the system.

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# SECTION I

## CONCLUSIONS

Low temperature caused a definite reduction in chlorine demand with the percent reduction essentially independent of effluent source.

Low temperature caused a marked reduction in the disinfecting ability of chlorine which varied significantly with effluents from different sources.

Temperature did not appreciably affect the relative rate of fecal and total coliform reduction in a particular effluent. In all cases, a lower chlorine residual and shorter contact time were required to meet the minimum fecal coliform criteria for effective disinfection than were required for minimum total coliform criteria.

Low temperature did not prevent minimally effective disinfection (1000 total and 200 fecal coliforms/100 ml) from being attained in effluents from all sources when batch disinfection was used.

To achieve satisfactory disinfection at low temperatures, the chlorine residual:contact time relationship must be determined for each effluent at the lowest temperature encountered in the system rather than use an arbitrary relationship as *prima facie* evidence of satisfactory disinfection.

## SECTION II

## RECOMMENDATIONS

Chlorine disinfection in flow through contact chambers must be studied at less than 1°C to determine the extent to which the enteric bacteria reduction:chlorine residual relationship is changed from that found in batch treatment.

The source and significance of "non-fecal" coliforms (those not giving a positive elevated temperature test) found in waste treatment systems during the winter should be determined.

Both total and fecal coliform criteria should continue to be used for establishing effective disinfection if receiving water quality is to be effectively maintained or enhanced.

Guideline criteria for attaining effective disinfection in low temperature effluents must be developed.

Evaluation of disinfectants, other than chlorine, for possible application in effluents having low temperatures should be accelerated.

## SECTION III

## INTRODUCTION

Chlorine is the disinfectant which has attained wide acceptance for use in treated wastewater disinfection, but the role of effluent temperature in the process has received insufficient emphasis. This presentation is limited to the low temperature aspects, and a more complete discussion of chlorine disinfection can be found in several recent publications (2, 6, 29). In addition to chlorine, there are several other disinfectants which have potential application in treated wastewater disinfection (2) and, some day, may also be widely accepted.

In 1936, Heathman et al. (16) studied the ability of chlorine and chloramine to kill pure cultures of enteric bacteria in tap water. Among other things, they compared this ability at room temperature and at the temperature of iced water. They concluded that, "The time required for chloramine and chlorine in some instances to kill strains of E. typhosa and members of the coli-aerogenes group is appreciably greater at low temperature than at room temperature." Subsequent work in the 1940's, 50's and 60's (see references 6 and 7) followed the lead of Heathman and co-workers and showed that low temperature hindered chlorine disinfection in pure culture:pure water systems. Chambers (6) recently reviewed chlorination of waste treatment plant effluents and pointed out the reason why disinfection studies had been conducted in this manner. He stated that, "Wastewater effluents contain many compounds and materials that interfere with the germicidal activity of chlorine, some of which completely neutralize it. Because of the many interferences in wastewater, it has been necessary to establish the inherent disinfecting characteristics of chlorine in highly purified water under the most carefully controlled and interference-free conditions possible."

Another study was also conducted in 1936 in which Rudolfs and Gehm (25) made a rather extensive study of sewage chlorination. They concluded that, "Within the limits of 5° and 37°C, neither bacterial reduction nor chlorine demand was appreciably affected by temperature in fresh or stale sewage." Since this early study, little attention has been given to directly studying disinfection in treated wastewater.

The need to study chlorine disinfection of treated wastewaters containing the inherent interferences was pointed out by Marais et al. in 1967 (21) when they stated that, "To date there have been no reliable laboratory studies on the efficiency of chlorine as a disinfectant in polluted waters, such as secondary sewage effluents which contain varying amounts of nitrogenous compounds and ammonia." Subsequently, there has been some study of wastewater disinfection (8, 19), but little effort has been directed toward temperature effect.

Chambers (6) pointed out that low water temperature severely limits the effectiveness of chlorine. This limitation poses a particularly serious problem in regions such as the Arctic and Subarctic where temperatures in some waste treatment systems, effluents from these systems and receiving waters are at or near 0°C during several months each winter. Thus, at low water temperatures, treated wastewater may contain more bacteria of fecal origin (9, 26). After entering the receiving water, the fecal indicator bacteria survive for longer periods at 0°C (14) than at warmer temperatures (3). The decreasing effectiveness of chlorine as a disinfectant and the higher number of fecal bacteria suggest that effluent disinfection may be more difficult to achieve at low temperatures. In addition, greater survival in cold receiving waters may mean requiring the discharge of fewer bacteria than is acceptable at warmer temperatures.

After considering the wide use of chlorine, the problems involved in low temperature treated wastewater disinfection and the research needs stated by Chambers and Berg (7), this study was designed to determine if effective disinfection could be attained in treated wastewater at less than 1°C (<1°C). The disinfection criteria developed by the Environmental Protection Agency, Region X (10) were used as the basis for establishing minimum effective disinfection. Briefly, these criteria are: [1] that effluents from chlorine contact chambers shall average less than 1000 total coliforms and 200 fecal coliforms/100 ml when the effluent is discharged into recreational waters; and [2] that the total chlorine residual shall not be less than 1 mg/l after 60 minutes of contact time when conclusive coliform data are not available.

Discussion of enteric parasites and viruses has been omitted because these groups of organisms are more resistant to chlorine than are bacteria of the coliform group [see the review by Chambers (6), for references and discussion].

## SECTION IV

## EXPERIMENTAL METHODS AND MATERIALS

### EFFLUENT SOURCES AND SAMPLING

Effluents from one primary sedimentation and three secondary biological waste treatment systems were examined during the winter of 1971-1972. The biological treatment systems were a 15 day detention time aerated lagoon and two extended aeration systems. One extended aeration system had submerged aeration and the other had surface aeration (oxidation ditch). Numerous extended aeration system (submerged aerator) effluent samples were used to develop the procedures followed throughout the remainder of the study. Both grab and 24-hour composite effluent samples were examined with no appreciable differences in coliform numbers or chlorine demand attributable to the sampling method. Samples were also examined in parallel at less than 1°C (<1°C) and at 25°C to determine what temperature effect could be expected. Disinfection results obtained at 25°C were consistent and compared favorably with other studies regardless of how the results varied at <1°C. Following this developmental work, only grab samples of the other three effluents were used, and the number of 25°C controls was kept to a minimum because of the timing problems encountered when extra samples were examined during the disinfection runs. One effluent sample was examined each week and each source was studied for three weeks.

### PROCEDURES FOR EFFLUENT PROCESSING

To obtain the necessary degree of experimental control, the following three day schedule was required for complete effluent analysis:

Day One:

A. Effluent collected in five gallon, polyethylene carboys between 7:00 and 9:00 a.m., and transported to the laboratory without delay.

B. Effluent temperature measured immediately after arrival in the laboratory.

C. Effluent transferred to a five gallon, glass carboy and stirred while being cooled to 0.0-0.5°C in a -10°C refrigerated water bath.

D. Effluent transferred to a 0°C room and stirred continuously until Day Two.

E. Sample withdrawn for preliminary coliform enumeration.

Day Two:

A. Preliminary coliform enumeration completed.

B. An immediate and one hour total chlorine demand established for the effluent at <1°C, and the amount of chlorine necessary to provide approximately 1 mg/l total chlorine residual after one hour contact time determined.

C. Effluent temperature was measured and samples were withdrawn for initial time coliform enumeration and physical and chemical parameter determinations.

D. For the disinfection run at <1°C, four effluent volumes of two or three liters each were set up as shown in Figures 1 and 2, and immersed in a refrigerated water bath set to maintain approximately 0°C in the bottles.

E. Chlorine dosing for the disinfection run at 0°C: [1] unchlorinated control, [2] sufficient chlorine injected into each of the other three bottles to provide approximately 0.5, 1.0 and 1.5 mg/l residual after one hour contact time.

F. Approximately four liters of effluent were warmed rapidly to 25°C, the pH determined and a sample withdrawn for initial coliform enumeration. For the disinfection run at 25°C, bottles containing one liter of effluent for the unchlorinated control and two liters to be dosed with the same amount of chlorine that should have given approximately 1.0 mg/l residual at 0°C after one hour contact time were set up on the laboratory bench as shown in Figure 1.

G. The <1°C and 25°C set-ups were completed concurrently and the contact period started as each bottle was dosed with chlorine. Total chlorine residual determination and coliform enumeration were conducted at predetermined intervals. At the end of the contact period, pH and temperature were measured in each bottle.

Day Three:

A. Coliform enumeration completed.

GLASSWARE PREPARATION

All glassware used during this study was made chlorine demand free (1) with the exception of the five gallon carboys. The glassware for use at <1°C was allowed to equilibrate at 0°C.

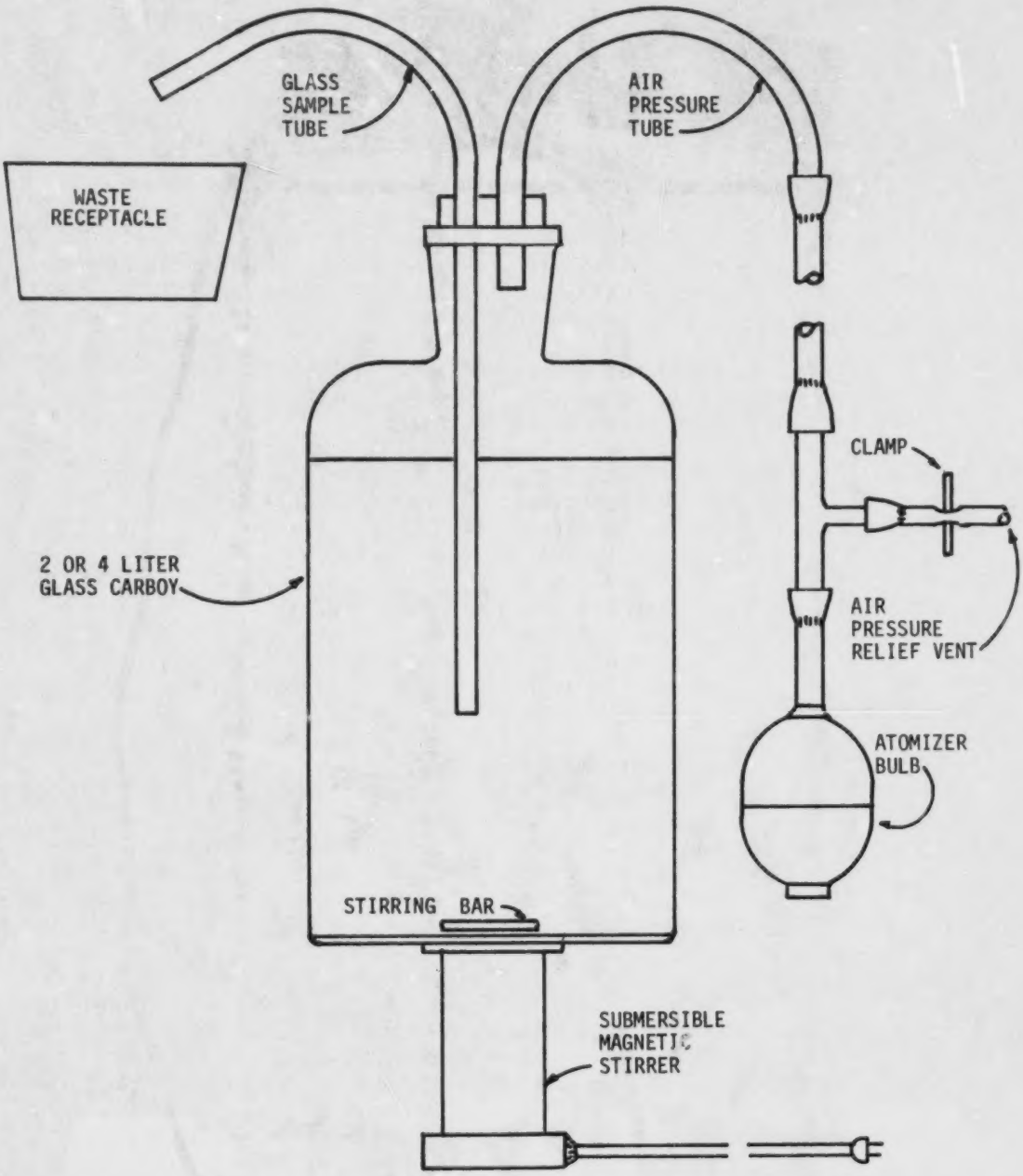


Figure 1. Schematic of batch treatment reactor vessel for chlorine disinfection studies

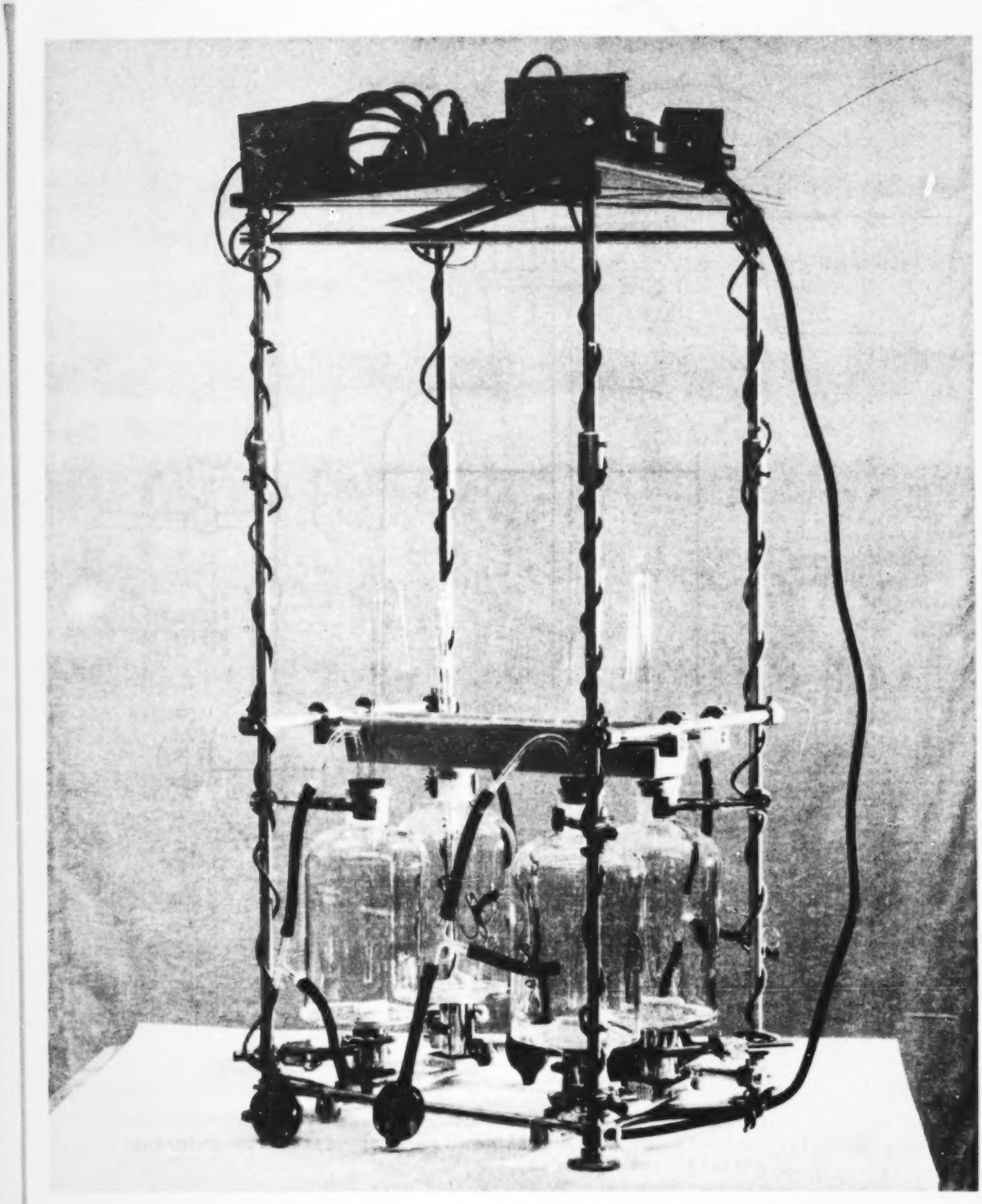

Figure 2. Reactor vessel set-up for chlorine disinfection studies at less than 1°C

## WATER PREPARATION

Distilled water from the building supply was filtered through a Barnstead Organic Removal cartridge followed by a Corning Ultra-High-Capacity demineralizer cartridge and then distilled in an all glass apparatus. Sufficient glass distilled water was prepared each week so that all water used in a disinfection run was from the same supply. The water for use at <1°C was allowed to equilibrate at 0°C.

## CHLORINATION METHOD

A chlorine stock solution containing approximately 500 mg/l total chlorine was freshly prepared from household bleach (Purex brand) and glass distilled water the day it was to be used. This solution was standardized by the iodometric method (1) and was then used for all chlorine dosages.

Effluent examination early in the study indicated that immediately after dosing, there was essentially no free available chlorine present as measured by the orthotolidine-arsenite (OTA) method (1). Therefore, all chlorine residual determinations were done in triplicate using the orthotolidine (OT) method (1) for measuring total chlorine residual. A Bausch and Lomb Spectronic 20 was used to measure the color intensity. All values were rounded to the nearest 0.1 mg/l for reporting in this study.

A pipet was used to deliver the chlorine stock solution when making temporary standards in distilled water. A syringe fitted with a 14 gauge cannula was used to add chlorine stock solution to all effluent samples so the total volume could be delivered rapidly. All stock solution additions were delivered directly into the vortex created by stirring with a magnetic stirrer.

## COLIFORM ENUMERATION

The membrane filter method (11) was used for both total and fecal coliform enumeration. M-Coliform Broth (BBL) and M-FC Broth (Difco) were the media used for total and fecal coliforms respectively. Each time the M-FC Broth was prepared, the pH was checked and adjusted to 7.4 as necessary.

All effluent samples for coliform enumeration were collected in sterile, 220 ml, polypropylene containers (Falcon Plastics) which contained 0.5 ml of a 10 percent sodium thiosulfate solution.

## PHYSICAL AND CHEMICAL PARAMETER MEASUREMENT

Chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), volatile suspended solids (VSS), total dissolved solids (TDS),

volatile dissolved solids (VDS), and total volatile solids (TVS) were determined by the methods described in Standard Methods for the Examination of Water and Wastewater, 13th Edition (1). Ammonia nitrogen ($NH_3$-N) was determined with Technicon AutoAnalyzer Methodology (27). The pH meters were fitted with combination electrodes and automatic temperature compensators.

## SECTION V

## EXPERIMENTAL RESULTS

### GENERAL

Physical and chemical parameters for all effluents examined are presented in Table 1. Some of these parameters have been considered among the most important in affecting chlorine demand and bactericidal activity in treated wastewater (5, 6, 23, 24). They appeared to be fairly consistent in samples from each source with the exception of COD, which varied over a wide range in both extended aeration systems. Although differences between systems were quite pronounced, only total suspended (TSS) and volatile suspended (VSS) solids could be related to the type of treatment (primary vs. secondary). The full range of solids data was not collected until after the extended aeration system (submerged aerator) effluent study had been completed. However, solids data from other work being conducted during the same time period suggested consistent results from the extended aeration system.

Effluents from systems operating at or near 0°C were not readily available in the Fairbanks area. Therefore, it was necessary to use effluents which arrived in the laboratory with temperatures ranging from 4.8-12.3°C (Table 1) and cool them to less than 1°C (<1°C). Since the ambient air temperature was low and the travel time was short, these were essentially the system operating temperatures when the samples were taken.

It has been pointed out that non-coliform bacteria and turbidity in chlorinated wastewater may interfere with coliform enumeration by the membrane filter method (1). Non-coliform bacteria caused little problem with fecal coliform enumeration, but occasionally did interfere with total coliform enumeration when there were more than 1000 total coliforms/100 ml. Since the minimum bacterial quality for effective disinfection was set at 1000 total and 200 fecal coliforms/100 ml of chlorinated effluent, sample volumes for filtration were generally selected so that 1000 total coliforms/100 ml was the maximum countable number thus minimizing the non-coliform interference. Under these conditions, total coliform numbers greater than 1000/100 ml were reported as Too Numerous To Count (TNTC). The sample volume that could be filtered was limited by suspended material which plugged the filter and/or built up on the surface obscuring the coliform colonies. To avoid these problems, the maximum effluent volume filtered was 8-12 ml with the result that many coliform counts were less than 20 per filter after disinfection. The validity of these low counts per filter may be questionable (1), but this was partially offset by filtering all effluent volumes in triplicate and reporting the average coliform number. For example, if a 10 ml sample was filtered and there were no colonies on any of the filters, the count/100 ml could only be reported as less than

Table 1. EFFLUENT CHEMICAL AND PHYSICAL CHARACTERISTICS

| Parameter | Effluent Source | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Primary Sedimentation# | | | Aerated Lagoon# | | | Extended Aeration Surface Aerator# | | Extended Aeration Submerged Aerator | | |
| | 2/10/72 | 2/17/72 | 3/2/72 | 4/6/72 | 4/13/72 | 4/20/72* | 3/9/72 | 3/23/72 | 12/2/71# | 12/9/71## | 12/16/71## |
| Temperature When Received (°C) | 10.2 | 9.7 | 9.8 | 4.8 | 12.3 | 7.1 | 7.9 | 11.6 | 9.2 | 8.9 | 8.0 |
| At Start of Contact Time | | | | | | | | | | | |
| TS (mg/l) | 530 | 490 | --- | 320 | 400 | 400 | 730 | 820 | --- | --- | --- |
| TSS (mg/l) | 92 | 96 | 89 | 27 | 33 | 43 | 37 | 44 | 35 | 43 | 37 |
| VSS (mg/l) | 65 | 71 | 69 | 21 | 29 | 35 | 30 | 35 | --- | --- | --- |
| TDS (mg/l) | 350 | 350 | 350 | 270 | 380 | 320 | 680 | 740 | --- | --- | --- |
| VDS (mg/l) | 140 | 150 | 150 | 150 | 140 | 190 | 210 | 150 | --- | --- | --- |
| TVS (mg/l) | 340 | 230 | 270 | 140 | 160 | 240 | 263 | 230 | --- | --- | --- |
| COD (mg/l) | 311 | 284 | 270 | 203 | 226 | 152 | 461 | 148 | 114 | 120 | 618 |
| $NH_3$-N (mg/l) | 21 | 22 | 23 | 20 | 21 | 21 | 19 | 22 | 15 | 20 | 22 |
| In 0°C Contact Chambers | | | | | | | | | | | |
| Initial Temperature (°C) | 0.2 | 0.0 | 1.6 | 1.3 | 1.0 | 0.6 | 2.2 | 0.5 | --- | --- | --- |
| Final Temperature (°C) | -0.2-+0.1 | 0.2-0.4 | 0.2-0.4 | 0.0-0.1 | 0.1-0.2 | 14.9-15.4* | -0.1-+0.2 | -0.1-0.0 | 0.4-0.6 | 0.3-0.5 | 0.9-1.0 |
| Initial pH | 6.9 | 6.9 | 6.8 | 7.0 | 6.8 | 7.1 | 7.1 | 7.1 | 7.4 | 7.2 | 7.9 |
| Final pH | 7.2-7.3 | 6.9-7.1 | 6.8-6.9 | 7.1-7.3 | 6.9-7.0 | 7.2-7.3 | 7.2-7.4 | 7.2-7.4 | 7.5-7.6 | 7.3-7.4 | 8.0-8.3 |
| In 25°C Contact Chambers | | | | | | | | | | | |
| Initial Temperature (°C) | 25.0 | --- | --- | --- | --- | 25.0 | ---** | ---** | --- | --- | 25.0 |
| Final Temperature (°C) | 25.0 | --- | --- | --- | --- | 25.0 | --- | --- | --- | --- | 25.5-25.6 |
| Initial pH | 6.9 | --- | --- | --- | --- | 7.2 | --- | --- | --- | --- | 7.5 |
| Final pH | 6.9-7.1 | --- | --- | --- | --- | 7.2-7.5 | --- | --- | --- | --- | 7.6-7.8 |

* Temperature control lost during the hour contact time at 0°C.
** No 25°C data for the oxidation ditch.
\# Grab sample.
## 24 hour composite sample.

10/100 (<10/100 ml). If the average count was five when 10 ml was filtered, the count was reported as 50/100 ml and footnoted as being based on an average of less than 20 colonies per filter.

Since this study was completed, Lin (20) has evaluated Most Probable Number (MPN) and membrane filter methods for total and fecal coliform enumeration in chlorinated effluents. His results indicated possible supression of both total and fecal coliform numbers when the membrane filter method was used with chlorinated effluents. Thus, the coliforms enumerated in chlorinated effluent during this study may have represented as little as two thirds of the actual number present.

The chlorine residual and bacterial results obtained at 25°C are shown in Table 2. It should be noted that the extended aeration results in this table are for the submerged aerator system only. Results from the surface aerator system have been omitted because the effluent was considered atypical at the time the 25°C work was scheduled. The effluent was black, anaerobic and contained 1000 mg/l total suspended solids (TSS). Time did not permit scheduling another run to include the 25°C portion.

At 25°C, all effluents had a high immediate chlorine demand followed by a much lower continuous demand throughout the contact period and a sharp decline in coliform numbers during the first 30 minutes of contact time. This was in close agreement with recent work conducted by Kott (19) at 20°C. The primary effluent had up to an order of magnitude greater total and fecal coliform numbers than did the other effluents and about twice the chlorine dosage was required to provide a similar residual after 30 and 60 minutes contact time. The 25°C results indicated: [1] the minimum bacterial quality for effective disinfection was met with ease in all effluents after 30 minutes of contact time; [2] both total and fecal coliforms had essentially disappeared after 60 minutes in the presence of 0.3-0.6 mg/l total chlorine residual; and [3] no apparent effect on final bacterial quality could be attributed to effluent source when similar chlorine residuals were maintained. Previously, corresponding observations have been made in operating treatment systems (18).

PRIMARY SEDIMENTATION EFFLUENT

The results in Table 3 were obtained at <1°C with effluents from a primary sedimentation system examined during three consecutive weeks. This system appeared to produce a consistent effluent as indicated by the solids and ammonia nitrogen concentrations (Table 1), and chlorine demand. Three effluent batches were dosed with chlorine during each run to ensure approximately a 1 mg/l total chlorine residual after one hour contact time. The required chlorine dosage was very close to 4.5 mg/l each week. The results indicated that the minimum effluent bacterial quality of 1000 total and 200 fecal coliforms/100 ml was easily attained

| Effluent Source †† | Date Sample Taken | Contact Time (min) | Unchlorinated | | | Chlorinated | | |
|---|---|---|---|---|---|---|---|---|
| | | | Total Chlorine Residual (mg/l)* | Total Coliforms (no./100 ml)** | Fecal Coliforms (no./100 ml)** | Total Chlorine Residual (mg/l)* | Total Coliforms (no./100 ml)** | Fecal Coliforms (no./100 ml)** |
| Primary Sedimentation | 2/10/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 5.0 mg/l | | |
| | | 0 | 0.0 | $5.5 \times 10^7$ | $5.6 \times 10^6$ | 1.7 | --- | --- |
| | | 15 | --- | --- | --- | 1.0 | --- | --- |
| | | 30 | --- | --- | --- | 0.7 | <390§ | <71§ |
| | | 45 | --- | --- | --- | 0.6 | --- | --- |
| | | 60 | 0.0 | $6.6 \times 10^7$ | $4.5 \times 10^6$ | 0.5 | <11§ | <8§ |
| Aerated Lagoon | 4/20/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 2.8 mg/l | | |
| | | 0 | 0.0 | $2.1 \times 10^7$ | $1.7 \times 10^5$ | 1.0 | --- | --- |
| | | 15 | --- | --- | --- | 0.9 | --- | --- |
| | | 20 | --- | --- | --- | --- | TNTC# | <10§ |
| | | 30 | --- | --- | --- | 0.8 | 600 | <10§ |
| | | 40 | --- | --- | --- | --- | 50† | <10§ |
| | | 45 | --- | --- | --- | 0.6 | --- | --- |
| | | 50 | --- | --- | --- | --- | 12† | <10§ |
| | | 60 | 0.0 | $1.8 \times 10^7$ | $2.1 \times 10^5$ | 0.6 | <13§ | <10§ |
| Extended Aeration*** | 12/16/71 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 2.4 mg/l | | |
| | | 0 | 0.0 | $6.8 \times 10^6$ | $2.8 \times 10^5$ | 0.7 | --- | --- |
| | | 30 | --- | --- | --- | 0.7 | 720† | <17§ |
| | | 60 | --- | --- | --- | 0.6 | 62† | <5§ |
| | | 90 | --- | --- | --- | 0.5 | 85† | 15† |
| | | 120 | --- | --- | --- | 0.5 | 25† | 5† |
| | | 240 | 0.0 | $5.7 \times 10^6$ | $5.3 \times 10^5$ | 0.3 | 15† | <5§ |

* Average of triplicate determinations.
** Average of coliform numbers on triplicate filters.
# TNTC = Too Numerous To Count, generally greater than 1000/100 ml of sample.
† Average of less than 20 coliform colonies/filter when triplicate filters were examined.
§ No coliform colonies on any filter when triplicate filters were examined.
†† No 25°C data for the oxidation ditch.
*** 24-hour composite sample; submerged aerator.

Table 2. CHLORINATED AND UNCHLORINATED DISINFECTION CONTROLS AT 25°C.

Table 3. PRIMARY SEDIMENTATION EFFLUENT DISINFECTION AT LESS THAN 1°C.

| Date Sample Taken | Contact Time (min) | Unchlorinated Control | | | Samples Receiving Various Chlorine Dosages | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) |
| 2/10/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 4.5 mg/l | | | Chlorine Dosage 5.0 mg/l | | | Chlorine Dosage 5.5 mg/l | | |
| | 0 | 0.0 | $4.7 \times 10^7$ | $4.1 \times 10^6$ | 1.4 | --- | --- | 1.6 | --- | --- | 2.2 | --- | --- |
| | 15 | --- | --- | --- | 0.9 | --- | --- | 1.7 | --- | --- | 2.0 | --- | --- |
| | 30 | --- | --- | --- | 0.9 | 5800† | <71§ | 1.4 | <385§ | <71§ | --- | <385§ | <71§ |
| | 45 | --- | --- | --- | 0.8 | --- | --- | 1.2 | --- | --- | 1.8 | --- | --- |
| | 60 | 0.0 | $3.4 \times 10^7$ | $2.7 \times 10^6$ | 0.9 | 51† | <8§ | 1.4 | 11† | 8† | 1.8 | <11§ | <8§ |
| 2/17/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 4.0 mg/l | | | Chlorine Dosage 4.5 mg/l | | | Chlorine Dosage 5.0 mg/l | | |
| | 0 | 0.0 | $2.8 \times 10^7$ | $1.4 \times 10^5$ | 1.0 | --- | --- | 1.3 | --- | --- | 1.7 | --- | --- |
| | 15 | --- | --- | --- | 0.6 | --- | --- | 1.2 | --- | --- | 1.5 | --- | --- |
| | 30 | --- | --- | --- | 0.6 | 350 | <10§ | 1.1 | 50† | <10§ | 1.5 | 50† | <10§ |
| | 45 | --- | --- | --- | 0.5 | --- | --- | 1.0 | --- | --- | 1.3 | --- | --- |
| | 60 | 0.0 | $2.4 \times 10^7$ | $4.6 \times 10^5$ | 0.5 | 20† | <10§ | 0.8 | 30† | <10§ | 1.2 | 10† | <10§ |
| 3/2/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 4.2 mg/l | | | Chlorine Dosage 4.7 mg/l | | | Chlorine Dosage 5.2 mg/l | | |
| | 0 | 0.0 | $2.9 \times 10^7$ | $4.9 \times 10^5$ | 1.1 | --- | --- | 1.6 | --- | --- | 1.9 | --- | --- |
| | 15 | --- | --- | --- | --- | TNTC# | 150† | 1.4 | TNTC# | <10§ | 1.7 | TNTC# | <10§ |
| | 20 | --- | --- | --- | --- | TNTC# | <10§ | --- | 160† | <10§ | --- | 88† | <10§ |
| | 25 | --- | --- | --- | --- | 310 | <10§ | --- | 25† | <10§ | --- | 13† | <10§ |
| | 30 | --- | --- | --- | 0.9 | 275 | <10§ | 1.2 | 25† | <10§ | 1.4 | 13† | <10§ |
| | 45 | --- | --- | --- | 0.7 | --- | --- | 1.3 | --- | --- | 1.6 | --- | --- |
| | 60 | 0.0 | $2.2 \times 10^7$ | $5.8 \times 10^5$ | 0.8 | 13† | <10§ | 1.1 | 13† | <10§ | 1.5 | 13† | <10§ |

# TNTC = Too numerous to count, generally greater than 1000/100 ml of sample.
† Average of less than 20 coliform colonies/filter when triplicate filters were examined.
§ No coliform colonies on any filter when triplicate filters were examined.

within the hour contact time when the total chlorine residual concentration was as low as 0.5 mg/l and in no case was more than 1 mg/l required. In two of the three runs, coliform numbers well below the minimum quality were achieved in no more than 30 minutes with less than 1 mg/l total chlorine residual. Coliforms were enumerated at five minute intervals from 15-30 minutes during the third run and the results indicated that more than 15 but less than 30 minutes contact time were required to reduce the total coliform count sufficiently to meet minimum effluent quality, while less than 15 minutes were required for fecal coliforms. Comparison of the 25°C results (Table 2) with the <1°C counterparts suggested that temperature effect on disinfection was minimal but there was a significant effect on chlorine demand in effluent from this source.

AERATED LAGOON EFFLUENT

Aerated lagoon effluent was examined for three consecutive weeks during which the solids and ammonia nitrogen (Table 1), and chlorine demand remained fairly constant. The major differences between this effluent and the primary effluent were that some components of the solids and COD appeared to be significantly higher in the primary effluent. When aerated lagoon effluent was first examined, it was assumed that disinfection would proceed at least as rapidly as primary effluent disinfection. However, this effluent was considerably more difficult to disinfect at <1°C than the primary effluent (Table 3). It was possible to disinfect the aerated lagoon effluent (Table 4) to a total and fecal coliform density which easily met the minimum bacterial quality after one hour contact time in the presence of approximately 1 mg/l total chlorine residual, but a contact time of at least 50 minutes was consistently required. When the final residual was appreciably greater than 1 mg/l, the contact time required to achieve minimum total coliform quality was shortened but variable from greater than 20 to greater than 40 minutes. Minimum total coliform quality was not reached during the hour when the final residual was appreciably less than 1 mg/l. Fecal coliforms were reduced to fewer than 200/100 ml in less than 30 minutes at all chlorine residual concentrations and possibly in less than 15 minutes in some cases. During the third run, temperature control was lost with a subsequent temperature rise from <1°C to 15°C. The probable effect of this temperature rise was an increased bacterial reduction and increased chlorine demand. When the 25°C results for this effluent (Table 2) were compared with the <1°C results, it was apparent that disinfection and chlorine demand were affected by temperature.

EXTENDED AERATION EFFLUENT (SUBMERGED AERATOR)

During the three consecutive weeks in which extended aeration system (submerged aerator) effluent was examined, both grab and composite samples were studied at <1°C. Little or no effect on the disinfection process could be attributed to the sampling method so it was assumed that the results presented in Table 5 were directly comparable. The physical and chemical parameters from this system suggested a fairly

Table 4. AERATED LAGOON EFFLUENT DISINFECTION AT LESS THAN 1°C.

| Date Sample Taken | Contact Time (min) | Unchlorinated Control | | | Samples Receiving Various Chlorine Dosages | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) |
| 4/6/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 2.1 mg/l | | | Chlorine Dosage 2.6 mg/l | | | Chlorine Dosage 3.1 mg/l | | |
| | 0 | 0.0 | $1.2 \times 10^6$ | $6.7 \times 10^4$ | 0.6 | --- | --- | 1.3 | --- | --- | 1.5 | --- | --- |
| | 15 | --- | --- | --- | 0.6 | TNTC# | TNTC# | 0.6 | TNTC# | TNTC# | 1.5 | TNTC# | 50† |
| | 20 | --- | --- | --- | --- | TNTC# | TNTC# | --- | TNTC# | 20† | --- | TNTC# | <10§ |
| | 25 | --- | --- | --- | --- | TNTC# | 420 | --- | TNTC# | 10† | --- | TNTC# | 20† |
| | 30 | --- | --- | --- | 0.5 | TNTC# | 130† | 1.0 | TNTC# | <10§ | 1.4 | TNTC# | <10§ |
| | 45 | --- | --- | --- | 0.6 | --- | --- | 0.6 | --- | --- | 1.4 | --- | --- |
| | 60 | 0.0 | $1.5 \times 10^6$ | $6.3 \times 10^4$ | 0.5 | TNTC# | 10† | 0.8 | 340 | <10§ | 1.4 | 25† | <10§ |
| 4/13/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 2.3 mg/l | | | Chlorine Dosage 2.8 mg/l | | | Chlorine Dosage 3.3 mg/l | | |
| | 0 | 0.0 | $3.9 \times 10^6$ | $3.3 \times 10^4$ | 0.8 | --- | --- | 1.1 | --- | --- | 1.6 | --- | --- |
| | 15 | --- | --- | --- | 0.6 | --- | --- | 1.2 | --- | --- | 1.6 | --- | --- |
| | 20 | --- | --- | --- | --- | TNTC# | 550 | --- | TNTC# | 140† | --- | TNTC# | 80† |
| | 30 | --- | --- | --- | 0.7 | TNTC# | 150† | 1.1 | TNTC# | 100† | 1.5 | TNTC# | <10§ |
| | 40 | --- | --- | --- | --- | TNTC# | 30† | --- | TNTC# | 10† | --- | 1200† | <10§ |
| | 45 | --- | --- | --- | 0.6 | --- | --- | 1.0 | --- | --- | 1.5 | --- | --- |
| | 50 | --- | --- | --- | --- | TNTC# | 30† | --- | 2600† | <10§ | --- | 250 | <10§ |
| | 60 | 0.0 | $3.8 \times 10^6$ | $4.5 \times 10^4$ | 0.6 | TNTC# | <10§ | 1.0 | 680 | <10§ | 1.4 | 75† | <10§ |
| 4/20/72* | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 2.3 mg/l | | | Chlorine Dosage 2.8 mg/l | | | Chlorine Dosage 3.3 mg/l | | |
| | 0 | 0.0 | $1.9 \times 10^7$ | $1.4 \times 10^5$ | 0.7 | --- | --- | 1.2 | --- | --- | 1.6 | --- | --- |
| | 15 | --- | --- | --- | 0.5 | --- | --- | 1.0 | --- | --- | 1.5 | --- | --- |
| | 20 | --- | --- | --- | --- | TNTC# | 10† | --- | TNTC# | <10§ | --- | TNTC# | <10§ |
| | 30 | --- | --- | --- | 0.5 | TNTC# | <10§ | 1.1 | TNTC# | <10§ | 1.4 | 62† | <10§ |
| | 40 | --- | --- | --- | --- | TNTC# | <10§ | --- | TNTC# | <10§ | --- | 12† | <10§ |
| | 45 | --- | --- | --- | 0.5 | --- | --- | 0.9 | --- | --- | 1.2 | --- | --- |
| | 50 | --- | --- | --- | --- | TNTC# | <10§ | --- | TNTC# | <10§ | --- | 12† | <10§ |
| | 60 | 0.0 | $2.3 \times 10^7$ | $2.5 \times 10^5$ | 0.4 | TNTC# | <10§ | 0.9 | 62† | <10§ | 1.4 | <13§ | <10§ |

* Temperature control lost during the hour contact time at 0°C.
\# TNTC =Too numerous to count, generally greater than 1000/100 ml of sample.
† Average of less than 20 coliform colonies/filter when triplicate filters were examined.
§ No coliform colonies on any filter when triplicate filters were examined.

Table 5. EXTENDED AERATION (SUBMERGED AERATOR) EFFLUENT DISINFECTION AT LESS THAN 1°C.

| Date Sample Taken | Contact Time (min) | Unchlorinated Control | | | Samples Receiving Various Chlorine Dosages | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) |
| 12/2/71* | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 1.4 mg/l | | | Chlorine Dosage 1.9 mg/l | | | Chlorine Dosage 2.4 mg/l | | |
| | 0 | 0.0 | $1.9 \times 10^6$ | --- | 0.4 | --- | --- | 0.7 | --- | --- | 1.2 | --- | --- |
| | 30 | --- | --- | --- | 0.4 | TNTC# | --- | 0.7 | TNTC# | --- | 1.1 | 8000 | --- |
| | 60 | --- | --- | --- | 0.2 | TNTC# | --- | 0.5 | 1200 | --- | 1.0 | 460† | --- |
| | 90 | --- | --- | --- | 0.1 | 1400 | --- | 0.4 | 580 | --- | 0.9 | 440 | --- |
| | 120 | --- | --- | --- | 0.3 | 940 | --- | 0.6 | 380 | --- | 1.0 | 300 | --- |
| | 240 | 0.0 | $1.8 \times 10^6$ | --- | 0.2 | 280 | --- | 0.5 | 180 | --- | 0.9 | 160 | --- |
| 12/9/71** | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 3.1 mg/l | | | Chlorine Dosage 3.6 mg/l | | | Chlorine Dosage 4.1 mg/l | | |
| | 0 | 0.0 | $2.0 \times 10^7$ | $2.5 \times 10^6$ | 1.4 | --- | --- | 1.7 | --- | --- | 2.3 | --- | --- |
| | 30 | --- | --- | --- | 1.1 | TNTC# | --- | 1.6 | TNTC# | --- | 2.1 | TNTC# | --- |
| | 60 | --- | --- | $3.6 \times 10^6$ | 1.2 | 3400 | 480 | 1.6 | 3000 | 360 | 2.1 | 2600 | 260 |
| | 90 | --- | --- | --- | 1.2 | 2800 | --- | 1.6 | 2700 | --- | 2.0 | 2300 | --- |
| | 120 | --- | --- | $1.5 \times 10^6$ | 1.2 | 2100 | 250 | 1.5 | 2100 | 150† | 1.8 | 1600† | 200 |
| | 240 | 0.0 | $2.9 \times 10^7$ | --- | 0.8 | 1700 | --- | 1.4 | 1200 | --- | 1.8 | 800 | --- |
| 12/16/71** | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 1.9 mg/l | | | Chlorine Dosage 2.4 mg/l | | | Chlorine Dosage 2.9 mg/l | | |
| | 0 | 0.0 | $5.6 \times 10^6$ | $7.8 \times 10^5$ | 0.7 | --- | --- | 1.0 | --- | --- | 1.4 | --- | --- |
| | 30 | --- | --- | --- | 0.5 | TNTC# | <37§ | 0.9 | TNTC# | <37§ | 1.3 | 2000† | <37§ |
| | 60 | --- | --- | --- | 0.4 | 1400 | 70† | 0.9 | 650 | 60† | 1.2 | 490 | 50† |
| | 90 | --- | --- | --- | 0.5 | 960 | 65† | 0.9 | 440 | 40† | 1.1 | 420 | 25† |
| | 120 | --- | --- | --- | 0.5 | 450 | 46† | 0.8 | 360 | 25† | 1.1 | 350 | 30† |
| | 240 | 0.0 | $7.6 \times 10^6$† | $4.2 \times 10^5$ | 0.4 | 300 | 20† | 0.7 | 230 | 10† | 1.0 | 210 | 10† |

# TNTC = Too numerous to count, generally greater than 1000/100 ml of sample.
† Average of less than 20 coliform colonies/filter when triplicate filters were examined.
§ No coliform colonies on any filter when triplicate filters were examined.
* Grab sample.
** 24 hour composite sample.

consistent effluent as did the chlorine dosage required to provide approximately 1 mg/l total chlorine residual after one hour contact time.

With this effluent, more than 30 minutes were required to meet the minimum total coliform quality for effective disinfection, but it was met without difficulty during the one hour contact period in two of the three runs when approximately 1 mg/l total chlorine residual remained. When the residual was appreciably less than 1 mg/l, the minimum quality was not achieved during the hour. Fecal coliform results were available for one of these two runs and the minimum quality was surpassed with ease in less than 30 minutes in the presence of approximately 0.5 mg/l total chlorine residual. Results from the third run were entirely different because minimum quality for neither total nor fecal coliforms was met after an hour contact period with a total chlorine residual of 2.1 mg/l. There may be some question as to when the minimum fecal coliform quality was attained during this run, but it appeared to require approximately 2 hours and 1.5-1.8 mg/l chlorine residual. The contact time was approaching 4 hours before minimum total coliform quality was achieved in the presence of a 1.8 mg/l residual.

The reason why effluent from this source should occasionally have been so difficult to disinfect is not clear but the results did suggest that some factors other than the measured parameters played a role. One point in which all three runs showed agreement was that coliform numbers continued to decrease after the first hour, but the rate was much lower than during the first hour of contact time.

Again, as with the aerated lagoon effluent (Table 4), this extended aeration effluent proved to be more difficult to disinfect than the primary effluent (Table 3) even though the chemical and physical parameters (Table 1) and the initial coliform numbers suggested that the primary effluent was of lower quality. It should also be noted that both chlorine demand and disinfection were significantly affected by increasing the temperature to 25°C (Table 2).

EXTENDED AERATION EFFLUENT (SURFACE AERATOR)

For three consecutive weeks, extended aeration system (surface aerator) effluent was examined in the same manner as effluents from other sources. As stated previously, the effluent was atypical during one week and there was not sufficient time for an extra run, so results from two runs are presented in Table 6. The chemical and physical parameters (Table 1) suggested that this was a fairly consistent effluent when the system was operating properly. There was sufficient spread between the chlorine dosages required to produce approximately a 1 mg/l total chlorine residual in the two runs that it could not be considered a consistent dosage.

Less than 30 minutes were required to meet the minimum bacterial quality

Table 6. EXTENDED AERATION (SURFACE AERATOR) EFFLUENT DISINFECTION AT LESS THAN 1°C.

| Date Sample Taken | Contact Time (min) | Unchlorinated Control | | | Samples Receiving Various Chlorine Dosages | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) | Total Chlorine Residual (mg/l) | Total Coliforms (no./100 ml) | Fecal Coliforms (no./100 ml) |
| 3/9/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 2.8 mg/l | | | Chlorine Dosage 3.3 mg/l | | | Chlorine Dosage 3.8 mg/l | | |
| | 0 | 0.0 | $6.8 \times 10^5$ | $9.3 \times 10^3$ | 1.0 | --- | --- | 1.4 | --- | --- | 2.0 | --- | --- |
| | 15 | --- | --- | --- | 0.9 | --- | --- | 1.4 | --- | --- | 1.9 | --- | --- |
| | 30 | --- | --- | --- | 0.9 | 90† | <10§ | 1.3 | 70† | <10§ | 1.8 | <10§ | <10§ |
| | 45 | --- | --- | --- | 0.9 | --- | --- | 1.4 | --- | --- | 1.7 | --- | --- |
| | 60 | 0.0 | $5.8 \times 10^5$ | $1.5 \times 10^4$ | 0.9 | 12† | <10§ | 1.3 | 12† | <10§ | 1.7 | <13§ | <10§ |
| 3/23/72 | | Chlorine Dosage 0.0 mg/l | | | Chlorine Dosage 3.0 mg/l | | | Chlorine Dosage 3.5 mg/l | | | Chlorine Dosage 4.0 mg/l | | |
| | 0 | 0.0 | $1.3 \times 10^7$ | $3.0 \times 10^5$ | 0.9 | --- | --- | 1.2 | --- | --- | 1.8 | --- | --- |
| | 15 | --- | --- | --- | 0.8 | TNTC# | 100† | --- | TNTC# | 90† | 1.6 | TNTC# | 30† |
| | 20 | --- | --- | --- | --- | TNTC# | 70† | --- | TNTC# | 50† | --- | 1300† | 30† |
| | 25 | --- | --- | --- | --- | TNTC# | 20† | --- | TNTC# | 10† | --- | 310 | 20† |
| | 30 | --- | --- | --- | 0.6 | 1000† | 20† | 0.9 | 630 | 10† | 1.6 | 160† | 20† |
| | 45 | --- | --- | --- | 0.6 | --- | --- | 1.0 | --- | --- | 1.5 | --- | --- |
| | 60 | 0.0 | $8.6 \times 10^6$ | $1.9 \times 10^5$ | 0.5 | 150† | 10† | 0.9 | 75† | 10† | 1.4 | 62† | <10§ |

# TNTC = Too numerous to count, generally greater than 1000/100 ml of sample.
† Average of less than 20 coliform colonies/filter when triplicate filters were examined.
§ No coliform colonies on any filter when triplicate filters were examined.

for effective disinfection in both runs when approximately 1 mg/l total chlorine residual remained after one hour of contact time, and as little as 0.5 mg/l residual was necessary to reduce the total coliforms to well below the minimum quality in less than 60 minutes contact time. The fecal coliforms had essentially disappeared in less than 30 minutes when the final total chlorine residual was approximately 1 mg/l. When the coliforms were enumerated at five minute intervals, the results suggested that the minimum fecal coliform quality was attained in less than 15 minutes and that the total coliform reduction required at least 25 minutes when the final total chlorine residual was approximately 1 mg/l. Of course, the rather large difference in the initial total and fecal coliform counts probably accentuated any differences in the results between the two runs.

## COMPARATIVE RESULTS

When results from the two extended aeration systems were compared, it was apparent that disinfection proceeded more rapidly in effluent from the surface aerator system (Table 6) than in the submerged aerator system (Table 5) at <1°C. Recorded physical and chemical parameter differences between these systems were not sufficiently pronounced to provide an explanation for these results. Even though disinfection did proceed more rapidly in the surface aerator system, the results were still not equal to those obtained with primary effluent (Table 3).

Primary effluents have been considered more difficult to disinfect to a predetermined coliform content than secondary effluents (6). This was borne out to the extent that greater chlorine dosages were required in the primary effluent (Tables 2 and 3) than in the secondary effluents (Tables 2, 4, 5 and 6) in order to satisfy the immediate chlorine demand and to provide the desired total chlorine residual. The consistently higher suspended solids concentration in the primary effluent (Table 1) may have accounted for the greater chlorine demand. However, a chlorine dosage of approximately 4.5 mg/l to provide 1 mg/l residual after one hour contact time in the primary effluent was not excessive when compared to the 2.4-4.0 mg/l dosages required in the secondary effluents.

When all chlorine dosages and all effluents were considered, it appeared that most of the one hour chlorine demand was satisfied in the first 1 to 2 minutes of contact time at <1°C and 25°C, with a much lower demand continuing throughout the hour. The portion of the one hour demand which was satisfied between dosing and first residual measurement was in excess of 80 percent in all except one aerated lagoon sample at <1°C and the primary effluent sample at 25°C. These were 72 and 73 percent of the one hour demand respectively.

Direct comparison of the 25°C results with the <1°C counterparts which received the same chlorine dosage showed that a much lower chlorine

residual remained after one hour contact time at 25°C and suggested that temperature had a rather pronounced effect on chlorine demand. Because of the greater demand at 25°C, the primary effluent one hour chlorine demand at <1°C was 80 percent of the corresponding 25°C demand, the aerated lagoon effluent demand was 86 percent and the extended aeration system (submerged aerator) effluent demand was 81 percent.

## SECTION VI

## DISCUSSION

The objective of this study was to determine if effective treated wastewater disinfection could be attained with chlorine at less than 1°C (<1°C). Results obtained with effluents from four waste treatment systems indicated that there were definite temperature effects. The most consistent of these effects was on chlorine demand, which was lower at <1°C than at 25°C by nearly the same percentage in effluents examined at both temperatures. The rate and/or extent of coliform reduction during the contact period was also lower at <1°C than at 25°C but the temperature effect ranged from no apparent effect in the primary effluent to a pronounced effect in the extended aeration system (submerged aerator) effluent. These temperature effects did not in themselves negate the effectiveness of chlorine as a disinfectant at temperatures as low as 0°C because the minimum criteria for effective disinfection were met with ease in effluents from all sources. The single exception to meeting the minimum quality was in one sample of extended aeration system (submerged aerator) effluent.

Extended aeration system (submerged aerator) and aerated lagoon effluents were the most difficult to disinfect at <1°C. Both of these systems were pilot plant operations located on a large military installation and, as a result, may have received waste containing some "atypical" components which interfered with the disinfection process. Although military waste may contain some components not normally found in "typical" civilian domestic waste, such a waste is not atypical in Alaska where a large number of military installations are located.

Batch treatment is essentially analogous to plug flow which does not simulate the course of events in most operating disinfection contact chambers. Batch treatment with continuous mixing and rapid chlorine injection, as used in this study, had several advantages over most operating contact chambers. The following were among these advantages: [1] chlorine was thoroughly and rapidly mixed with the effluent; [2] chamber configuration ensured that all effluent remained in contact with the chlorine throughout the contact period; and [3] theoretical and actual contact time were the same. In addition, the effluent chlorine demand was determined immediately prior to treatment. Thus, higher bacterial quality could be expected after the contact period in this system than in most operating systems which are plagued with short-circuiting problems and are usually designed for average rather than maximum flow contact time.

During the winter months, climatic conditions in interior Alaska effectively seal all exposed soil and water surfaces, making it unlikely that coliform bacteria enter waste treatment systems from other than sewered

locations. The source of coliforms can probably be further restricted because there are no industries in the area which contribute unusually large coliform numbers in the wastes they produce. Thus, coliforms apparently come almost entirely from domestic wastes, suggesting that a large portion of the total coliform population should give a positive elevated temperature fecal coliform test. Throughout this study, the fecal coliforms consistently represented a smaller portion of the total coliform population than could have been expected if no alterations occurred (12). There are at least three possible explanations for an altered coliform population. Although there is no supporting evidence, one possible explanation is that the coliform population in the human intestinal tract is modified when living in a cold environment. The other two explanations are related to the warm temperature encountered in the sewage collection and treatment systems during this study. One of these is differential die-off of fecal and non-fecal coliforms with the fecal coliform viability being reduced more rapidly. The other possible explanation was derived from observations during a study currently in progress which suggested some differential growth enhancement at the 8-10°C temperatures in the collection and treatment systems with some portion of the non-fecal coliform population increasing in numbers while the fecal coliform numbers remained nearly constant (15). Similar observations suggesting enteric bacteria growth in 5-10°C river water were made by Hendricks and Morrison (17).

Geldreich (12) presented a very comprehensive discussion in which he pointed out the significance of the fecal coliform portion of the total coliform population. He showed that the portion of the total coliform population which did not give a positive fecal coliform test had only a small chance of originating in warm blooded animal feces, whereas coliforms which gave a positive test had very little chance of being from any other source. Because of this and a more recent compilation of water quality criteria (22), there is a current effort to place more emphasis on fecal coliform numbers and de-emphasize or possibly not use total coliform numbers when determining the bacterial quality of treated wastewater and surface water (13). This effort could possibly have the effect of permitting an increased discharge of non-fecal coliforms to the receiving water, since the results obtained in this study indicated that the minimum fecal coliform quality of 200/100 ml was consistently met with a lower chlorine residual and in a shorter contact time than was the 1000/100 ml minimum total coliform quality at <1°C. The fact that the fecal coliforms were present in 1-2 orders of magnitude lower numbers than total coliforms may have accounted for the differences. However, the results did suggest that the fecal coliforms may have been somewhat more susceptable to chlorine disinfection than was the non-fecal portion of the total coliform population.

When chlorinated effluents from several sources were compared, it became evident that the disinfecting ability of chlorine varied signifi-

cantly at <1°C. Thus, an arbitrary chlorine residual after a predetermined contact time cannot be considered prima facie evidence of satisfactory disinfection, and the chlorine residual:contact time relationship must be established for each effluent to be disinfected (6) at the lowest effluent temperature encountered. In any event, the only real measure of satisfactory disinfection is the number of enteric bacteria being discharged into the receiving water. In batch treatment, the theoretical and actual contact times are the same. This is not true in many operating contact chambers. Because of short-circuiting problems, theoretical contact time has very little meaning and inadequately disinfected effluent may be discharged into a receiving water. The resulting public health hazards have been well documented (22). These hazards acquire greatly increased significance in low temperature receiving waters because of enhanced enteric bacteria survival (14, 28), and because many people consume surface water without benefit of any form of treatment in Alaska.

Residual chlorine toxicity to aquatic life in receiving waters is beyond the scope of this discussion. There is a considerable body of literature from temperate climates indicating that very low levels of chlorine and compounds containing chlorine are toxic to aquatic life (4). However, there has been no determination of toxic effects in receiving waters approaching 0°C, and under the additional stress of severely depleted dissolved oxygen. Therefore, it is essential that extreme caution be exercised in maintaining chlorine residuals no higher and possibly lower than those established as being non-toxic in warmer receiving waters until low temperature bioassay studies have been conducted under Arctic and Subarctic conditions.

## SECTION VII

## REFERENCES


1. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 13th Edition. New York, American Public Health Association, 1971. 874 p.

2. American Society of Civil Engineers. Proceedings of the National Specialty Conference on Disinfection. New York, American Society of Civil Engineers, 1970. 705 p.

3. Ballentine, R. K., and F. W. Kittrell. Observations of Fecal Coliforms in Several Recent Stream Pollution Studies. In: Proceedings of the Symposium on Fecal Coliform Bacteria in Water and Wastewater. Bureau of Sanitary Engineering, California State Department of Public Health, 1968. p. 80-126.

4. Brungs, W. A. Effects of Residual Chlorine on Aquatic Life: Literature Review. Journal Water Pollution Control Federation. In Press.

5. Burns, R. W., and O. J. Sproul. Virucidal Effects of Chlorine in Wastewater. Journal Water Pollution Control Federation. 39:1834-1849, November 1967.

6. Chambers, C. W. Chlorination for Control of Bacteria and Viruses in Treatment Plant Effluents. Journal Water Pollution Control Federation. 43:228-241, February 1971.

7. Chambers, C., and G. Berg. Disinfection and Temperature Influences. In: International Symposium on Water Pollution Control in Cold Climates, Murphy, R. S., and D. Nyquist (eds.). Environmental Protection Agency, Fairbanks, Ak. Publication Number 16100 EXH 11/71. November 1971. p. 312-328.

8. Collins, H. F., R. E. Selleck, and G. C. White. Problems in Obtaining Adequate Sewage Disinfection. In: Proceedings of the National Specialty Conference on Disinfection. New York, American Society of Civil Engineers, 1970. p. 137-161.

9. Coutts, H. J., and C. Christianson. Extended Aeration in Cold Regions. Environmental Protection Agency, Fairbanks, Ak. In Preparation. 1973.

10. Environmental Protection Agency, Region X. Disinfection Criteria and Design Guidelines. Environmental Protection Agency, Seattle, Wa. December 1970. 6 p.

11. Federal Water Pollution Control Administration. Current Practices in Water Microbiology. Federal Water Pollution Control Administration, Cincinnati, Ohio. February 1970.

12. Geldreich, E. E. Sanitary Significance of Fecal Coliforms in the Environment. Federal Water Pollution Control Administration, Cincinnati, Ohio. Publication Number WP-20-3. November 1966. 122 p.

13. Geldreich, E. E. Personal Communication. Environmental Protection Agency, Cincinnati, Ohio. 1973.

14. Gordon, R. C. Winter Survival of Fecal Indicator Bacteria in a Subarctic Alaskan River. Environmental Protection Agency, Fairbanks, Ak. Publication Number EPA-R2-72-013. August 1972. 41 p.

15. Gordon, R. C., C. V. Davenport, and B. H. Reid. Unpublished Data. Environmental Protection Agency, Fairbanks, Ak. 1973.

16. Heathman, L. S., B. S. Pierce, and P. Kabler. Resistance of Various Strains of E. typhi and Coli Aerogenes to Chlorine and Chloramine. Public Health Reports. 51:1367-1387, October 1936.

17. Hendricks, C. W., and S. M. Morrison. Multiplication and Growth of Selected Enteric Bacteria in Clear Mountain Stream Water. Water Research (Oxford). 1:567-576, August/September 1967.

18. Heukelekian, H., and S. D. Faust. Compatibility of Wastewater Disinfection by Chlorination. Journal Water Pollution Control Federation. 33:932-942, September 1961.

19. Kott, Y. Chlorination Dynamics in Wastewater Effluents. In: Proceedings of the National Specialty Conference on Disinfection. New York, American Society of Civil Engineers, 1970. p. 585-608.

20. Lin, S. Evaluation of Coliform Tests for Chlorinated Secondary Effluents. Journal Water Pollution Control Federation. 45:498-506, March 1973.

21. Marias, A. F., E. M. Nupen, G. J. Stander, and J. R. H. Hoffman. A Comparison of the Inactivation of Escherichia coli I and Polio Virus in Polluted and Unpolluted Waters by Chlorination. In: International Conference on Water for Peace. 1967. p. 670-689.

22. Mechalas, B. J., K. K. Hekimian, L. A. Schinazi, and R. H. Dudley. Water Quality Criteria Data Book, Vol. 4, An Investigation into Recreational Water Quality. Environmental Protection Agency, Washington, D. C. Publication Number 18040 DAZ 04/72. April 1972. 256 p.

23. Monroe, D. W., and D. C. Phillips. Chlorine Disinfection in Final Settling Basins. In: Proceedings of the National Specialty Conference on Disinfection. New York, American Society of Civil Engineers, 1970. p. 163-177.

24. Rhines, C. E. Fundamental Principles of Sewage Chlorination. In: Proceedings, 20th Industrial Waste Conference. Lafayette, Purdue University, 1965. p. 673-678.

25. Rudolfs, W., and H. W. Gehm. Sewage Chlorination Studies. Bulletin 601. New Jersey Agricultural Experiment Station. March 1936. 72 p.

26. Slanetz, L. W., C. H. Bartley, T. G. Metcalf, and R. Nesman. Survival of Enteric Bacteria and Viruses in Municipal Sewage Lagoons. In: 2nd International Symposium for Waste Treatment Lagoons, McKinney, R. E. (ed.). Meseraull Printing, Inc., 1970. p. 132-141.

27. Technicon Corp. Ammonia in Water and Waste Water. Industrial Method IND-18-69W, Technicon AutoAnalyzer Methodology. Technicon Corp., Tarrytown, N. Y., 1969.

28. Van Donsel, D., R. C. Gordon, and C. V. Davenport. Unpublished Data. Environmental Protection Agency, Fairbanks, Ak. 1973.

29. White, G. C. Handbook of Chlorination. New York, Van Nostrand Rheinhold Co., 1972. 744 p.

## SECTION VIII

## GLOSSARY

Anaerobic - Condition under which no free oxygen is present.

Arctic - Area north of the 10°C isotherm for the warmest month and the -10°C isotherm for the coldest month of the year.

Bactericidal - Killing or having the power to kill bacteria.

Batch Treatment - A quantity of effluent disinfected in such a manner that all portions receive the same exposure to the disinfectant.

Chloramine - Any compound containing an ammonia molecule in which one or more chlorine atoms has replaced hydrogen atoms in the ammonia portion of the compound.

Chlorine Demand - The difference between the amount of chlorine added to an effluent and the amount measured as total chlorine after a specified contact time.

Chlorine Residual - The amount of chlorine remaining in an effluent and measurable as total chlorine after a specified contact time.

COD (Chemical Oxygen Demand) - Measure of the oxygen equivalent of that portion of the organic matter in an effluent sample that is susceptible to oxidation by a strong chemical oxidant.

Composite Sample - Equal effluent volumes collected at selected time intervals and pooled throughout a predetermined time span to provide the final sample for analysis.

Contact Chamber - A chamber in which the effluent and chlorine are continuously mixed for a specified length of time to achieve disinfection.

Contact Time (Period) - The length of time effluent and chlorine are held in the contact chamber.

Disinfectant - An agent which destroys harmful bacteria.

Disinfection - The act or process of destroying harmful bacteria.

Domestic Waste - Water carried waste which is mostly from kitchen, bathroom, lavatory, toilet and laundry.

Effluent - Liquid portion of the waste which is discharged from a waste treatment system or contact chamber.

Enteric Bacteria - Bacteria which inhabit the lower intestinal tract of humans or other warm-blooded animals.

Fecal Coliform - A total coliform bacteria subgroup which is specifically found in the feces of humans and other warm-blooded animals.

Germicidal - See disinfectant definition.

Grab Sample - Effluent sample taken for analysis at one point in time as opposed to composite sample.

Parameter - A determination which defines the condition of the system relative to that determination.

Plug Flow - Ideal continuous flow in which all of the effluent has the same residence time.

Primary Waste Treatment - The removal of settleable organic and inorganic solids by the process of sedimentation.

Pure Culture - A single strain or species of bacteria free from other bacteria.

Receiving Water - Body of water into which the liquid portion of the treated wastewater is discharged.

Secondary Waste Treatment - Treatment of sewage by biological methods following primary treatment.

Short-Circuiting - The extent to which portions of the effluent entering the contact chamber at the same time receive less than theoretical contact time.

Solids - Residue remaining after various treatments of the effluent, i.e. evaporation of water.

Subarctic - Areas where the mean temperature is higher than 10°C for less than four months of the year and the mean temperature for the coldest month is less than 0°C.

Survival (Bacterial) - Continuation of viability under adverse conditions.

Temperate Climate - Any area north of the Tropic of Cancer not previously defined as Arctic or Subarctic.

Theoretical Contact Time - The length of time that a volume of effluent and chlorine are in the contact chamber if no short-circuiting occurs.

Total Coliform - Heterogenous group of bacteria which meet certain morphological and biochemical criteria, and are found in feces of human and other warm-blooded animals, as well as in other environmental situations.

Unit Process - Distinct operations which are employed to produce an effluent of the desired quality.

Viability - The capacity of bacterial cells to grow and reproduce if appropriate conditions are present.